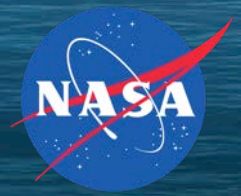
Understanding Spatial and Temporal Variations of Arctic Circulation Using Oxygen Isotopes of Seawater

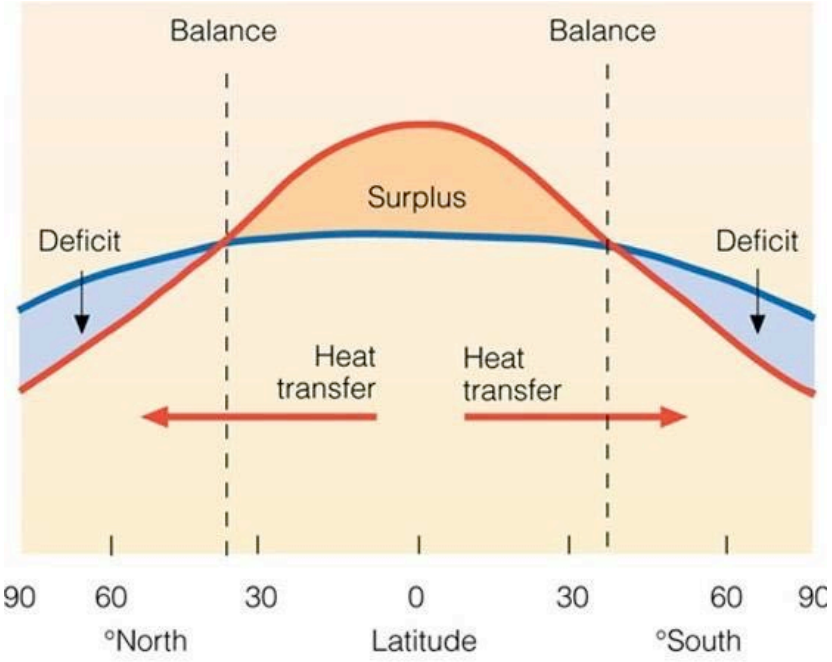
Undergraduate: Leon Yin
High School Student: Cassandra Kopans-Johnson
High School Teacher: Susan Meabh Kelly
Researcher: Allegra LeGrande



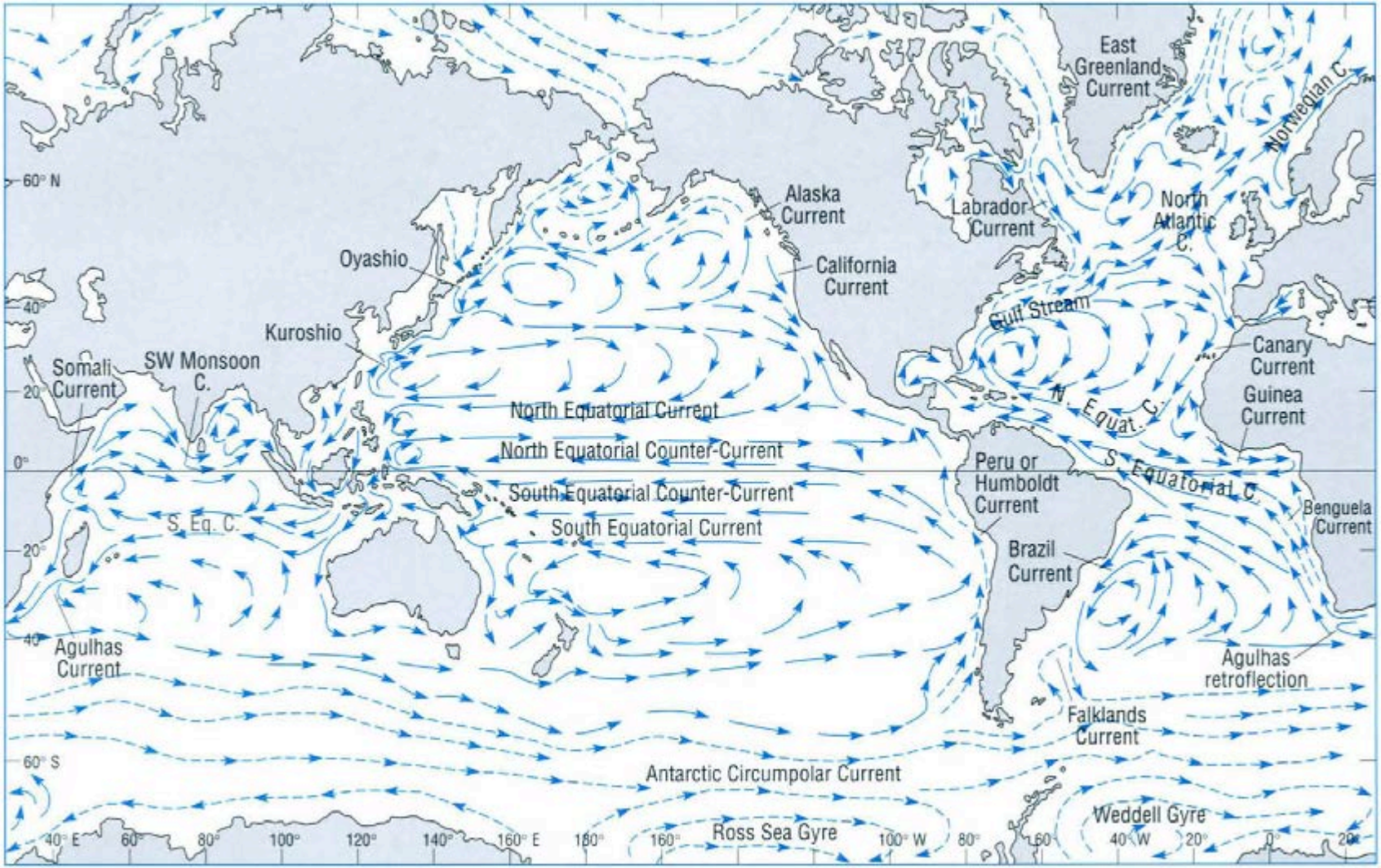
http://www.midoceanpartners.com/i/ocean_still.jpg

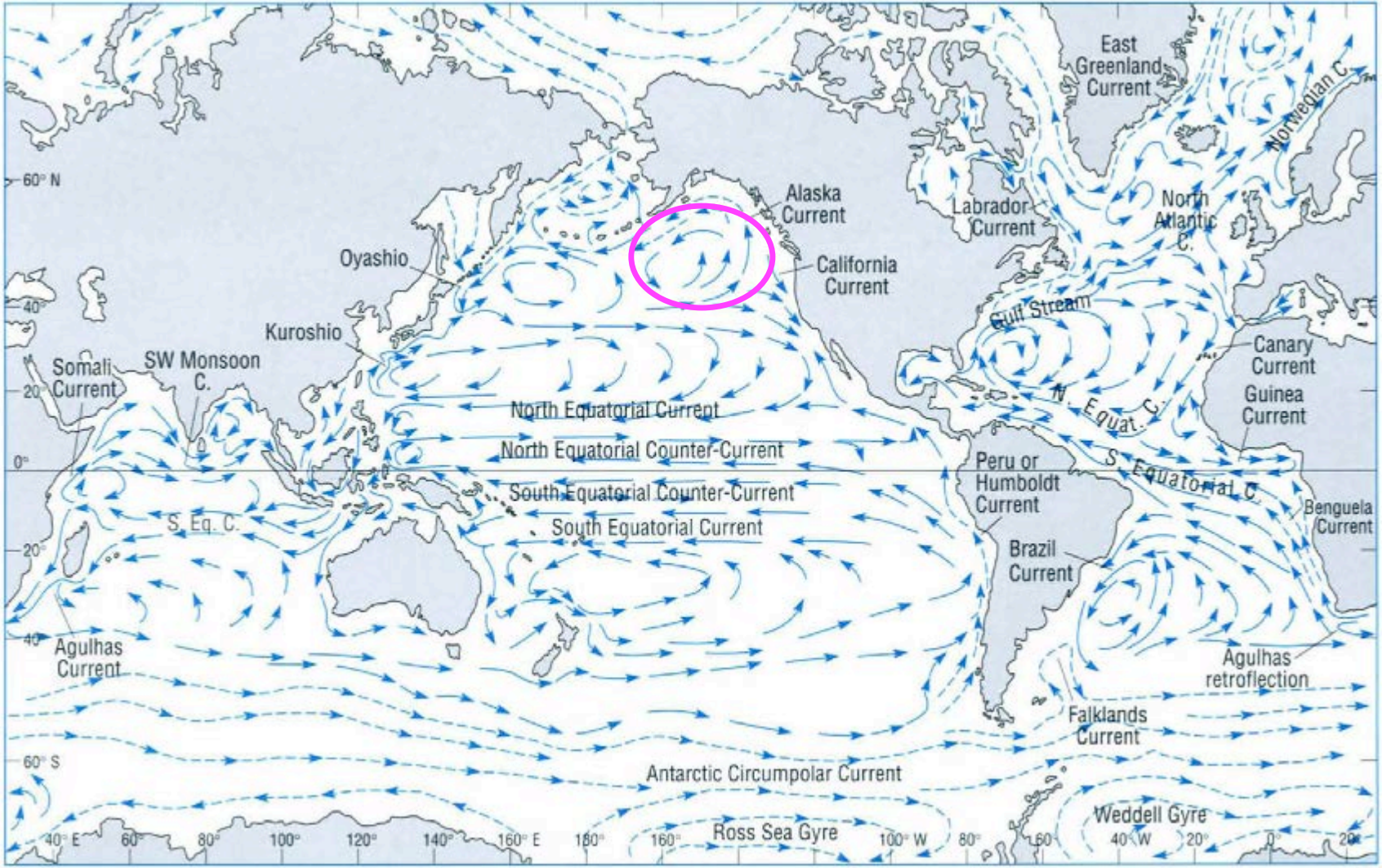
Purpose of Climate

- Earth has a heat budget.
- As solar radiation bombards it, equatorial regions absorb more heat while polar regions absorb less heat.
- Earth redistributes heat through atmospheric and **oceanic** circulation.



https://www.e-education.psu.edu/files/earth540/image/Lesson4/HeatRedist.png


East Greenland Current
Norwegian C.
60° N
Alaska Current
Labrador Current
North Atlantic C.
Oyashio
California Current
40°
Gulf Stream
Kuroshio
Canary Current
Somali Current
SW Monsoon C.
20°
North Equatorial Current
N. Equat. C.
Guinea Current
North Equatorial Counter-Current
0°
Peru or Humboldt Current
S. Equatorial C.
South Equatorial Counter-Current
Benguela Current
S. Eq. C.
South Equatorial Current
20°
Brazil Current
40°
Agulhas Current
Agulhas retroflection
Falklands Current
60° S
Antarctic Circumpolar Current
Weddell Gyre
40° E
60°
80°
100°
120°
140°
160° E
180°
160°
Ross Sea Gyre
100° W
80°
60°
40° W
20°
0°
20°

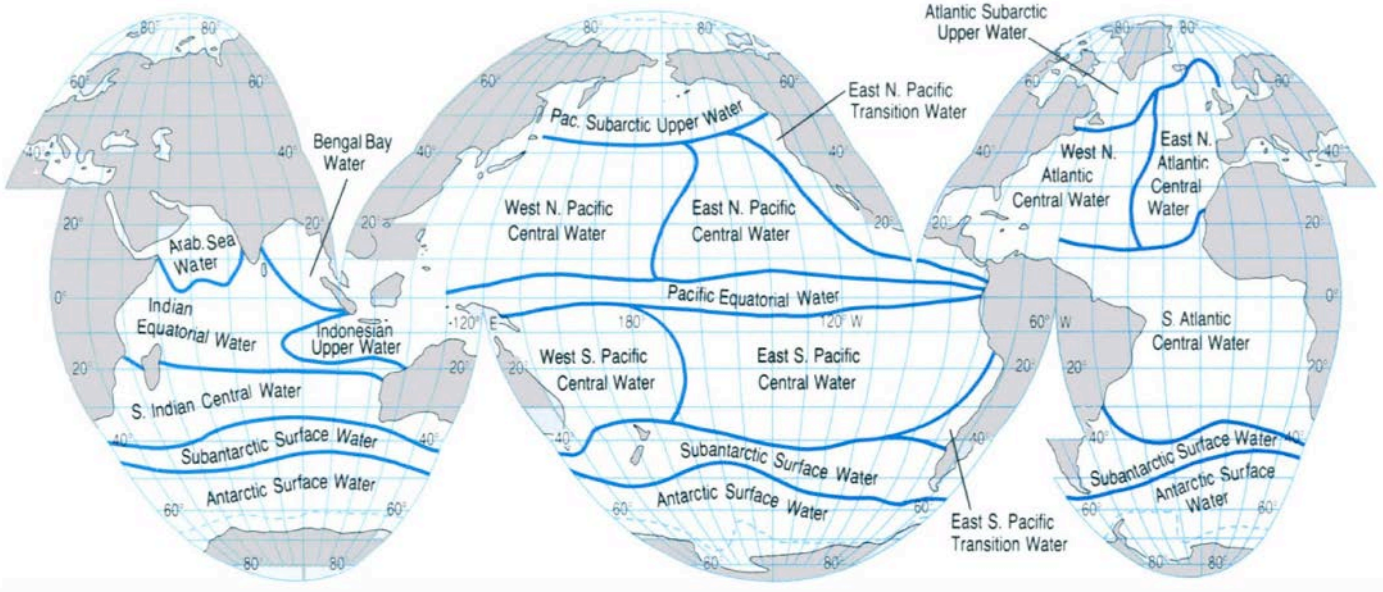

East Greenland Current
Norwegian C.
60° N
Alaska Current
Labrador Current
North Atlantic C.
Oyashio
California Current
40°
Gulf Stream
Kuroshio
Canary Current
Somali Current
SW Monsoon C.
20°
North Equatorial Current
N. Equat. C.
Guinea Current
North Equatorial Counter-Current
0°
Peru or Humboldt Current
S. Equatorial C.
South Equatorial Counter-Current
Benguela Current
S. Eq. C.
South Equatorial Current
20°
Brazil Current
40°
Agulhas Current
Agulhas retroflection
Falklands Current
60° S
Antarctic Circumpolar Current
Weddell Gyre
40° E
60°
80°
100°
120°
140°
160° E
180°
160°
Ross Sea Gyre
100° W
80°
60°
40° W
20°
0°
20°

Water Masses

Regional pockets are surface sources for water mass formation.

⬇

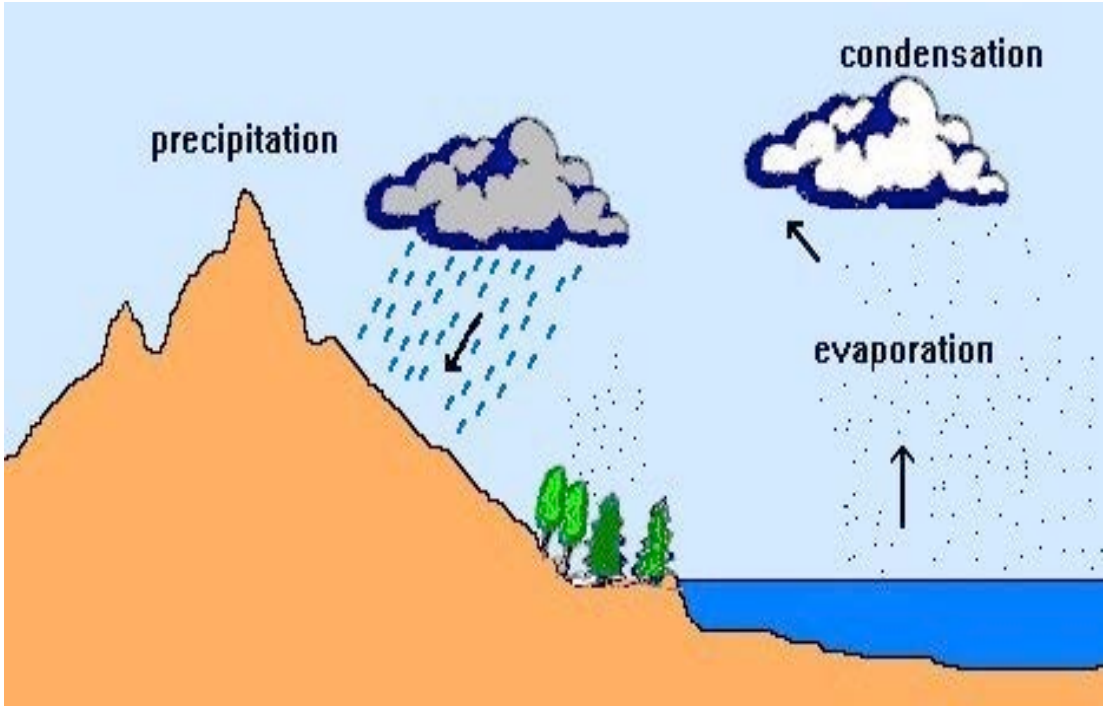
They trigger thermohaline circulation, density driven oceanic circulation.



Defining $\delta^{18}O$

- ^{18}O =
  - Heavy isotope of oxygen
  - A semi-conserved tracer of the hydrologic cycle due to its regional relationship with salinity
- In standard ocean water ($R_{standard}$),
  For each 1,000,000 $H_2{}^{16}O$ molecules
  ~2005 $H_2{}^{18}O$ molecules
- ‘delta’ notation:
  $\delta^{18}O$ in permil (‰) ≡ ($R_{sample}/R_{standard}$ -1) X1000

Rayleigh Distillation



^{18}O (heavy)
hard to evaporate,
easy to precipitate
→ salt water

^{16}O (light)
easy to evaporate,
hard to precipitate
→ fresh water

Fairbanks and Charles 1992

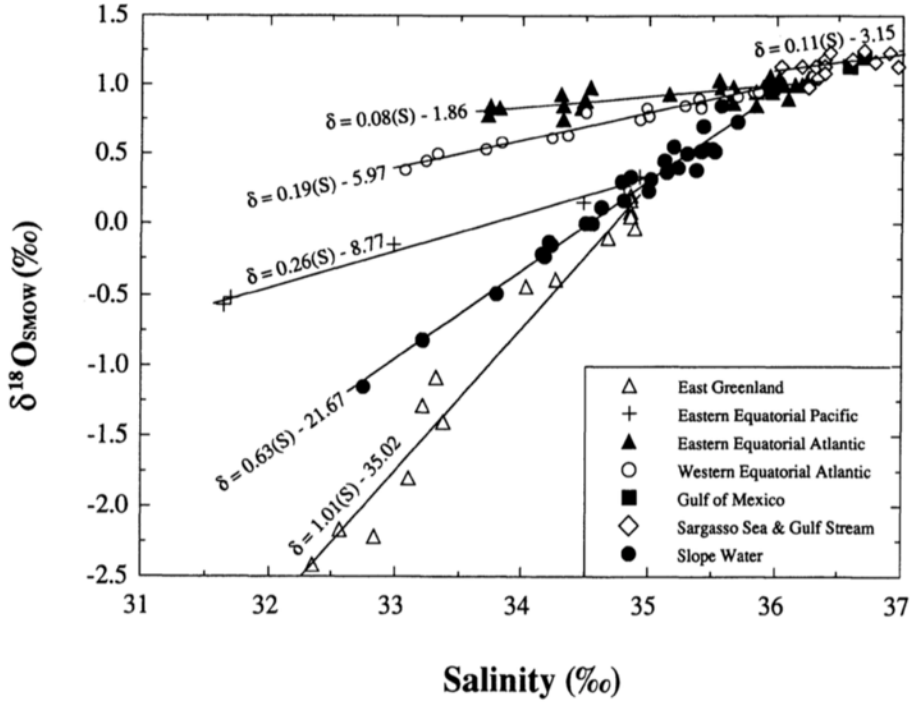


Fig 30.3B. Plots of $\delta^{18}O$ and salinity measurements across all major salinity gradients in the Atlantic and eastern tropical Pacific (Fairbanks, ms in preparation)

Research Context

Scientists have been using ^{18}O water isotopologues as tracers of the hydrologic cycle to better understand ocean circulation.

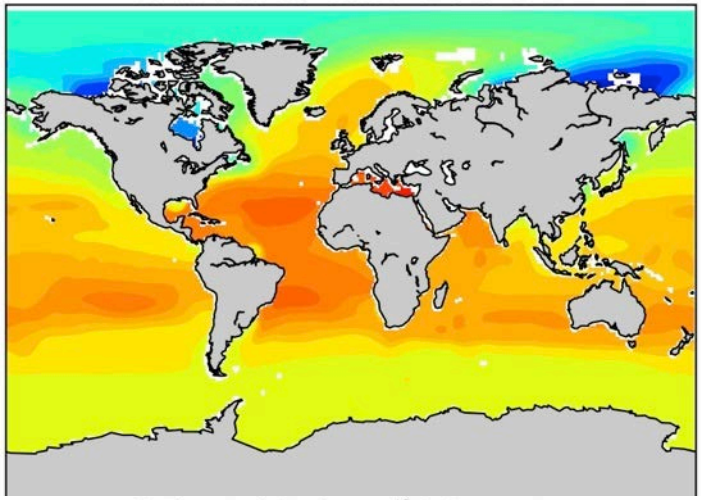
Previous Work

- **Database: (1999)** G. Schmidt et al
- **Gridded dataset: (2006)** A. LeGrande and G. Schmidt

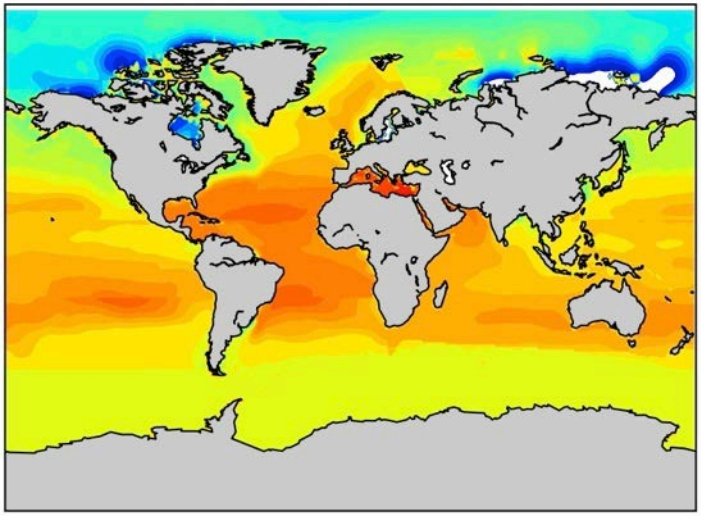
Our Work

- Update the database.
- Examine spatial and temporal impact on ^{18}O in the Arctic.
- Improve regional ^{18}O-S relationships to redefine Arctic water masses

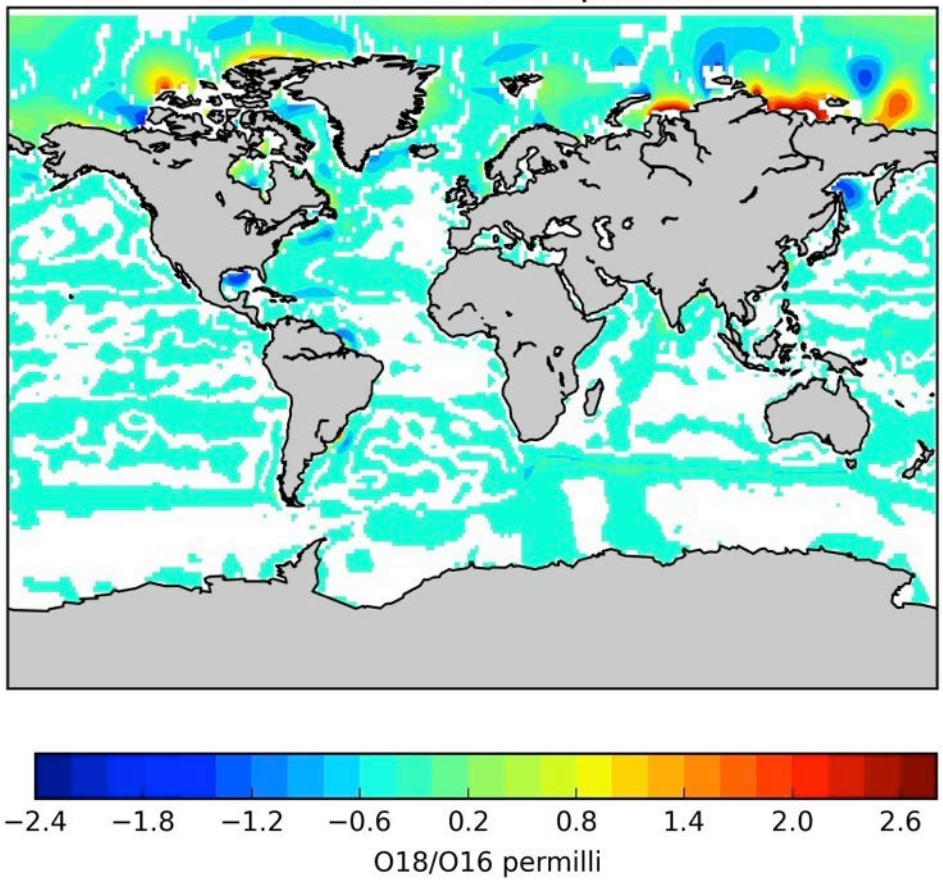
Calculated Surface δ^{18}O Seawater



Estimated Surface δ^{18}O Seawater

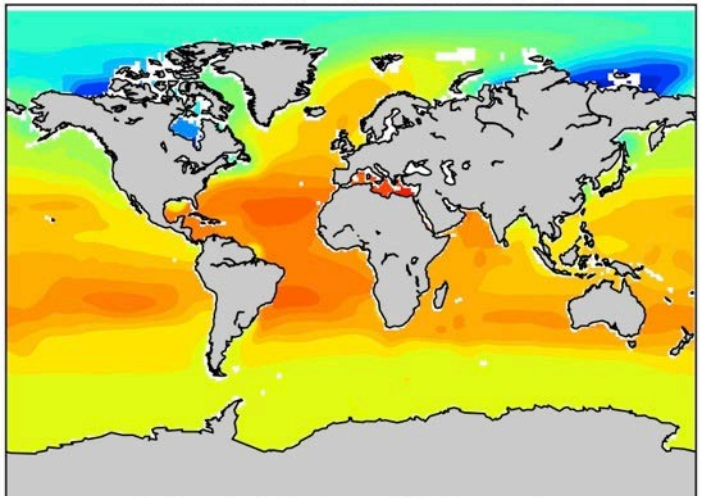


δ^{18}O Est-Calc Discrepencies

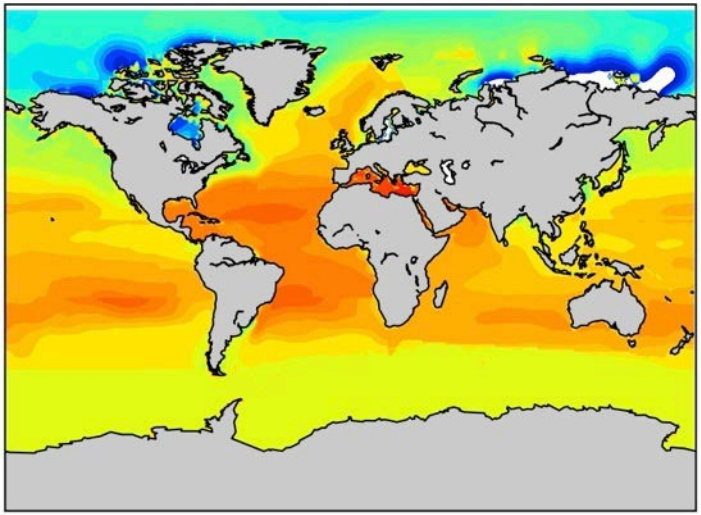


A. LeGrande and G. Schmidt and this project's updates

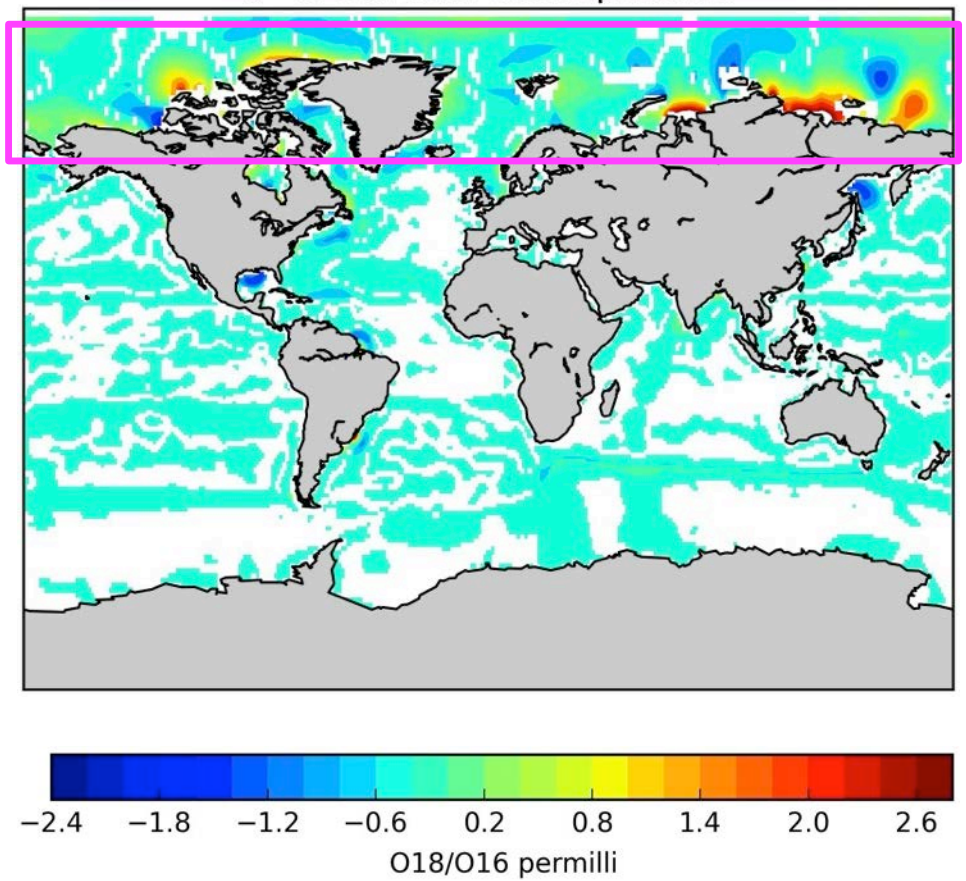
Calculated Surface δ^{18}O Seawater



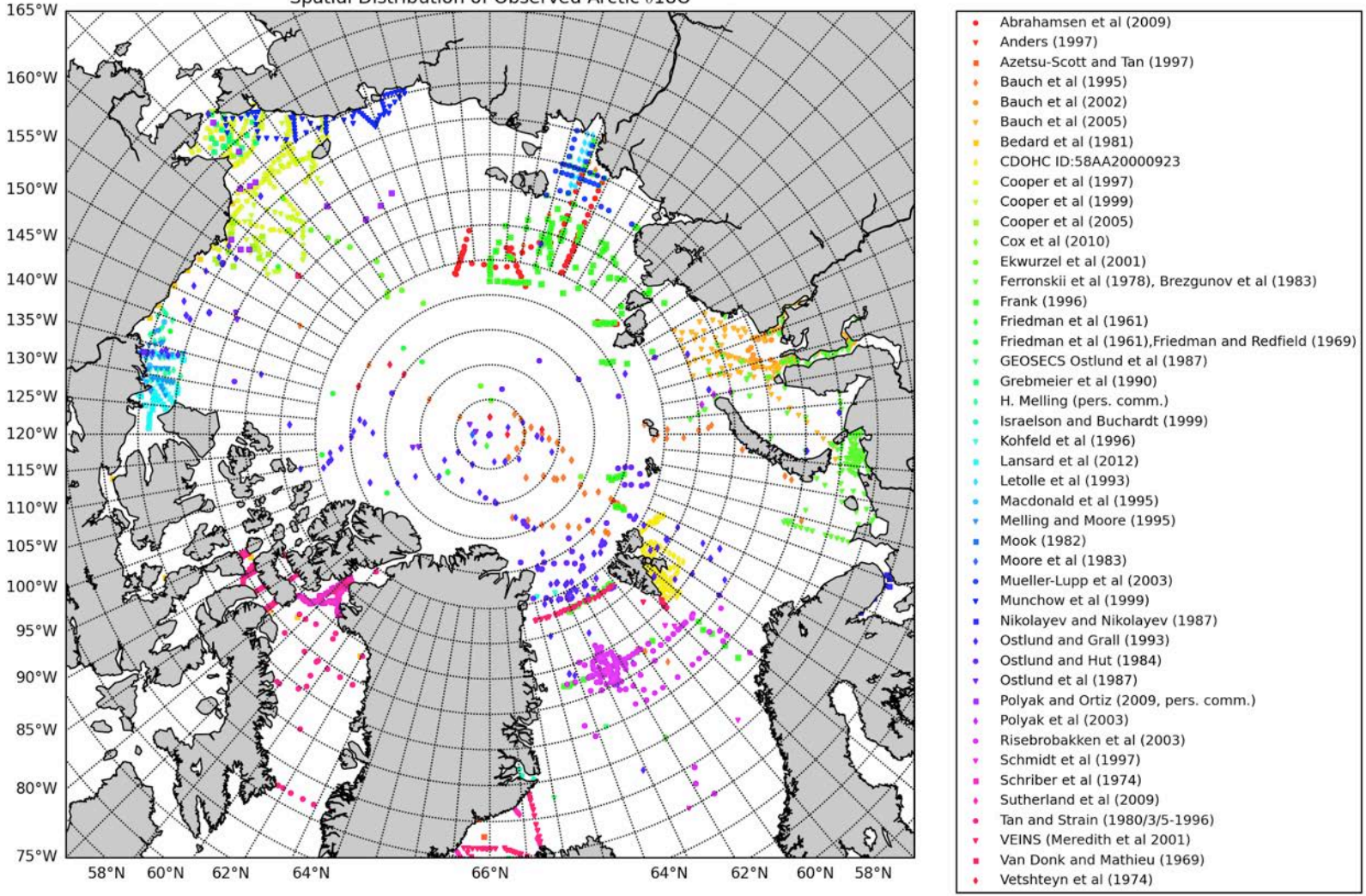
Estimated Surface δ^{18}O Seawater

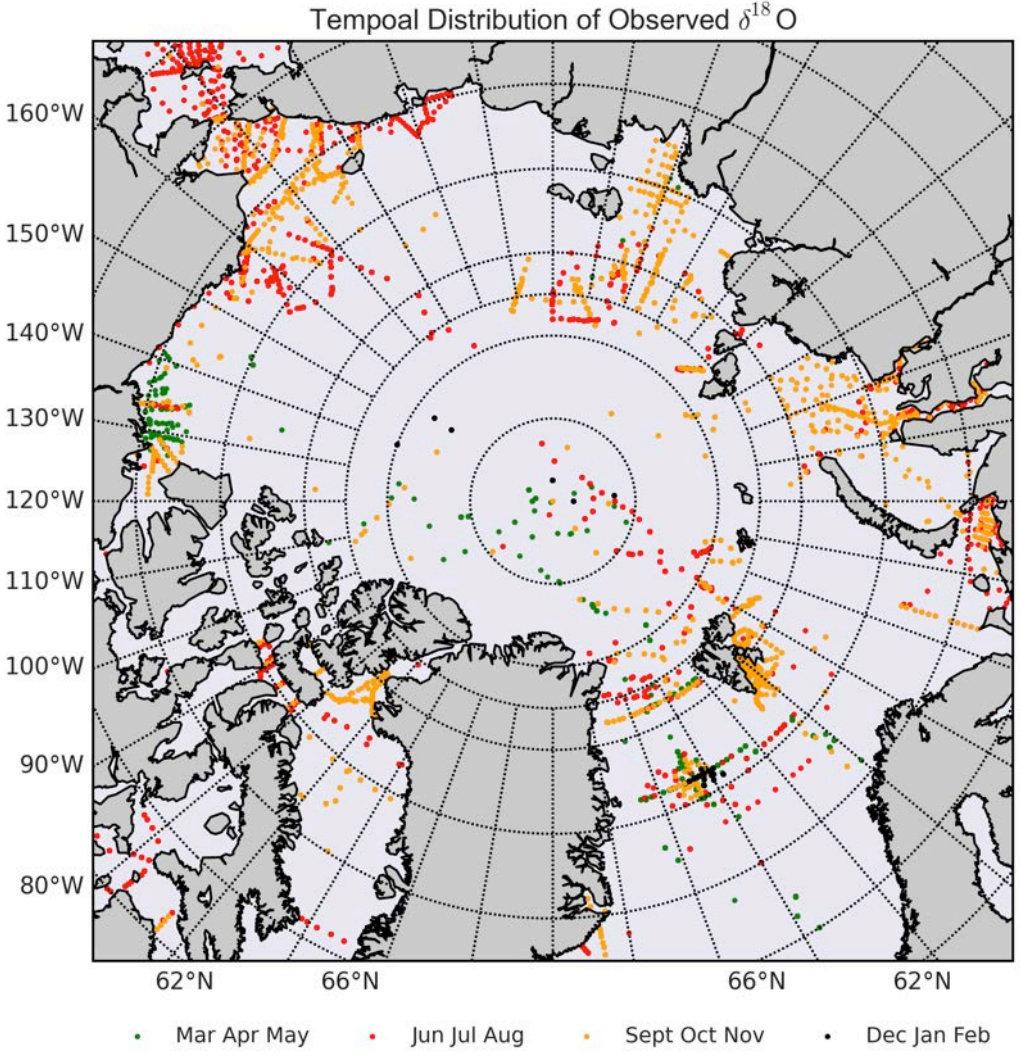


δ^{18}O Est-Calc Discrepencies



A. LeGrande and G. Schmidt and this project's updates


Spatial Distribution of Observed Arctic δ18O
165°W
160°W
155°W
150°W
145°W
140°W
135°W
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
58°N
60°N
62°N
64°N
66°N
64°N
62°N
60°N
58°N
Abrahamsen et al (2009)
Anders (1997)
Azetsu-Scott and Tan (1997)
Bauch et al (1995)
Bauch et al (2002)
Bauch et al (2005)
Bedard et al (1981)
CDOHC ID:58AA20000923
Cooper et al (1997)
Cooper et al (1999)
Cooper et al (2005)
Cox et al (2010)
Ekwurzel et al (2001)
Ferronskii et al (1978), Brezgunov et al (1983)
Frank (1996)
Friedman et al (1961)
Friedman et al (1961),Friedman and Redfield (1969)
GEOSECS Ostlund et al (1987)
Grebmeier et al (1990)
H. Melling (pers. comm.)
Israelson and Buchardt (1999)
Kohfeld et al (1996)
Lansard et al (2012)
Letolle et al (1993)
Macdonald et al (1995)
Melling and Moore (1995)
Mook (1982)
Moore et al (1983)
Mueller-Lupp et al (2003)
Munchow et al (1999)
Nikolayev and Nikolayev (1987)
Ostlund and Grall (1993)
Ostlund and Hut (1984)
Ostlund et al (1987)
Polyak and Ortiz (2009, pers. comm.)
Polyak et al (2003)
Risebrobakken et al (2003)
Schmidt et al (1997)
Schriber et al (1974)
Sutherland et al (2009)
Tan and Strain (1980/3/5-1996)
VEINS (Meredith et al 2001)
Van Donk and Mathieu (1969)
Vetshteyn et al (1974)


Tempoal Distribution of Observed δ^{18}O
160°W
150°W
140°W
130°W
120°W
110°W
100°W
90°W
80°W
62°N
66°N
66°N
62°N
Mar Apr May
Jun Jul Aug
Sept Oct Nov
Dec Jan Feb

Spatial Distribution

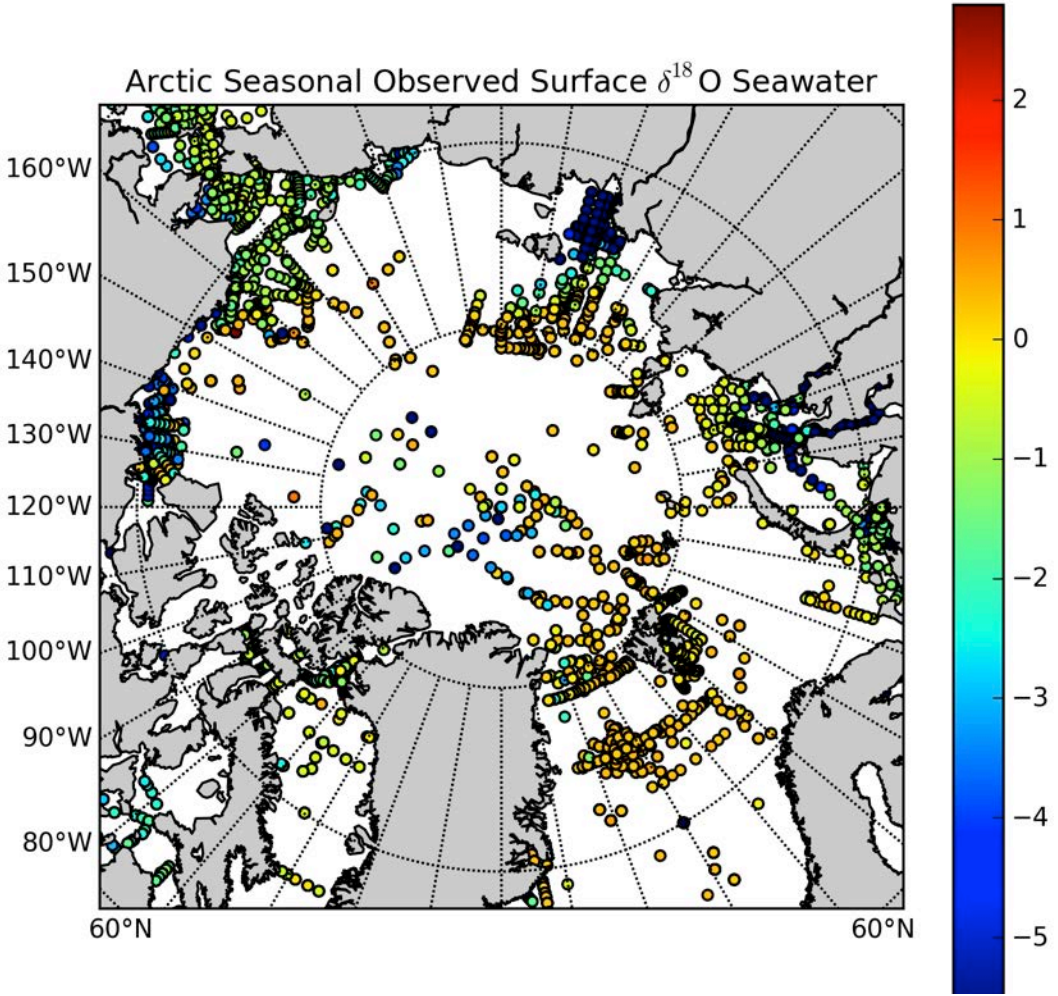
Coastal water - Open water

⬇

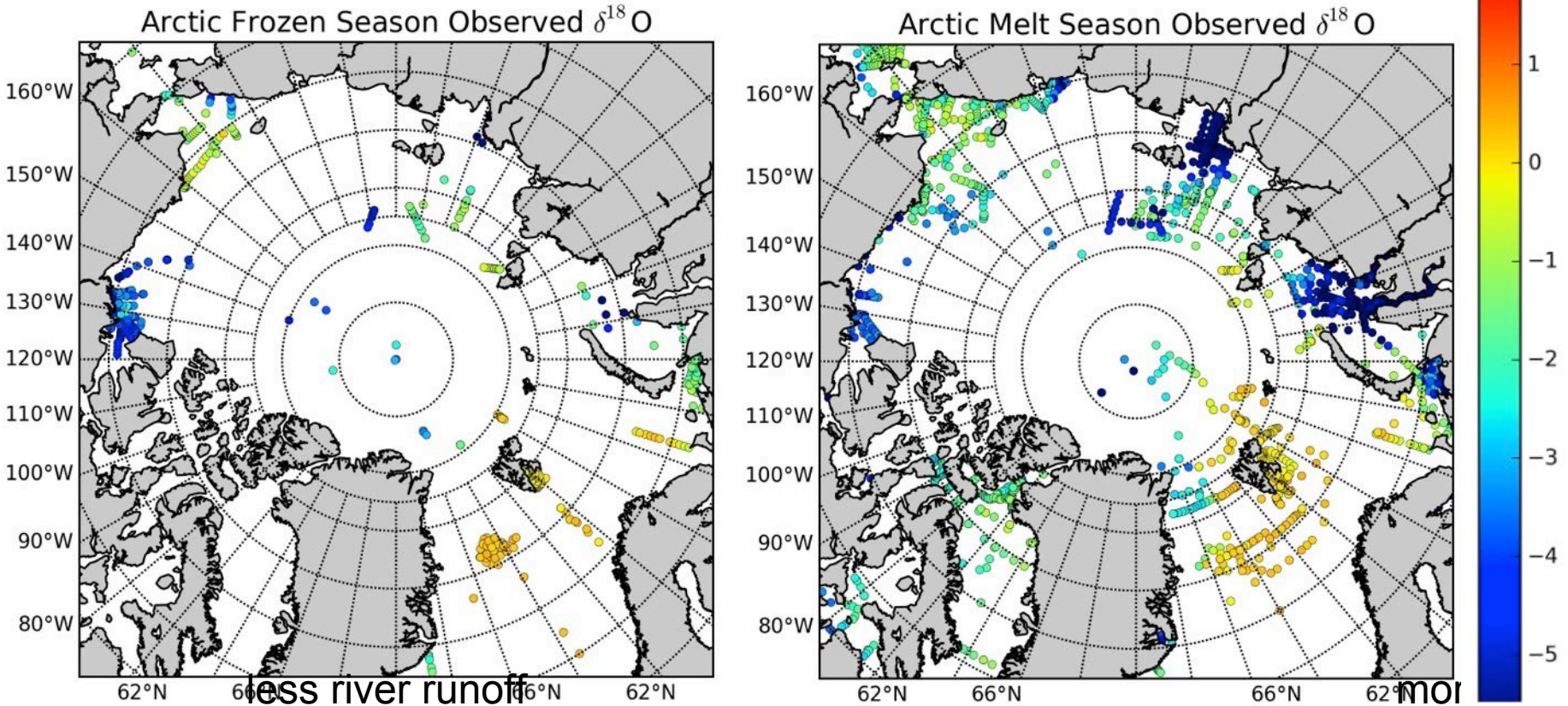
River runoff

=

Rayleigh Distillation and resulting inland freshwater discharge with lower $\delta^{18}O$.



Temporal Distribution

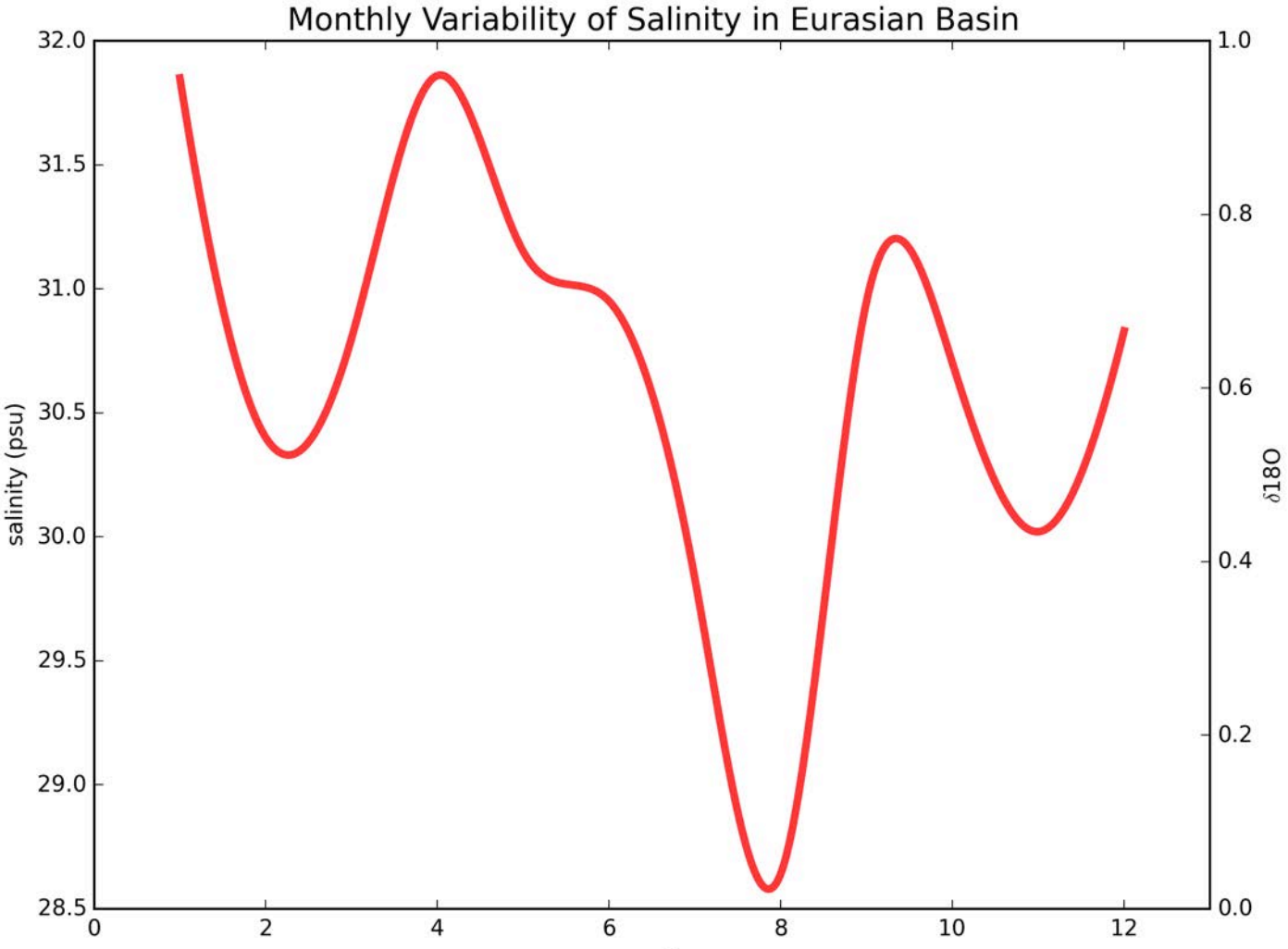


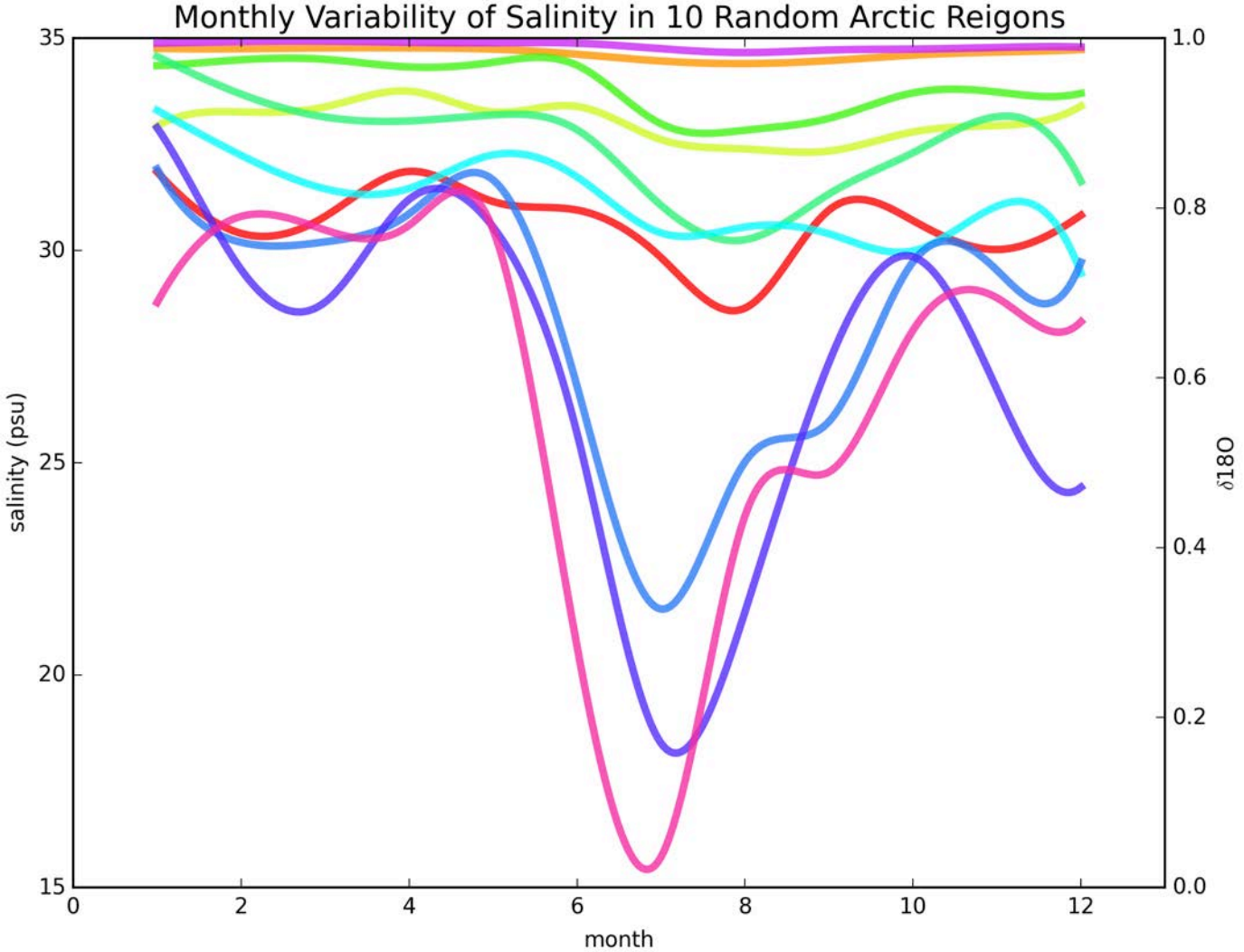
less river runoff

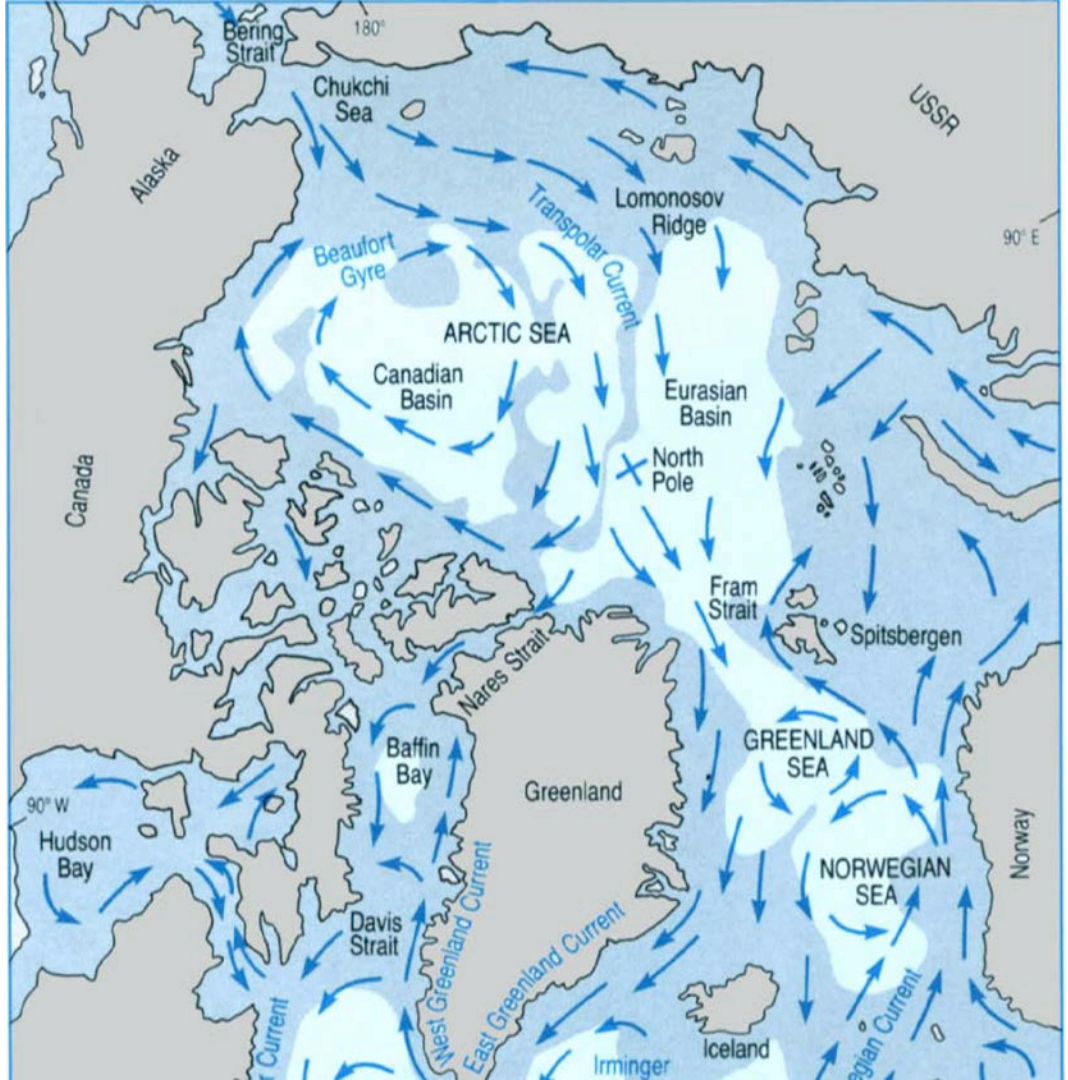
river runoff

mor

^{18}O Levels


Monthly Variability of Salinity in Eurasian Basin
salinity (psu)
δ18O
32.0
31.5
31.0
30.5
30.0
29.5
29.0
28.5
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12


Monthly Variability of Salinity in 10 Random Arctic Reigons
salinity (psu)
δ18O
month
35
30
25
20
15
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12

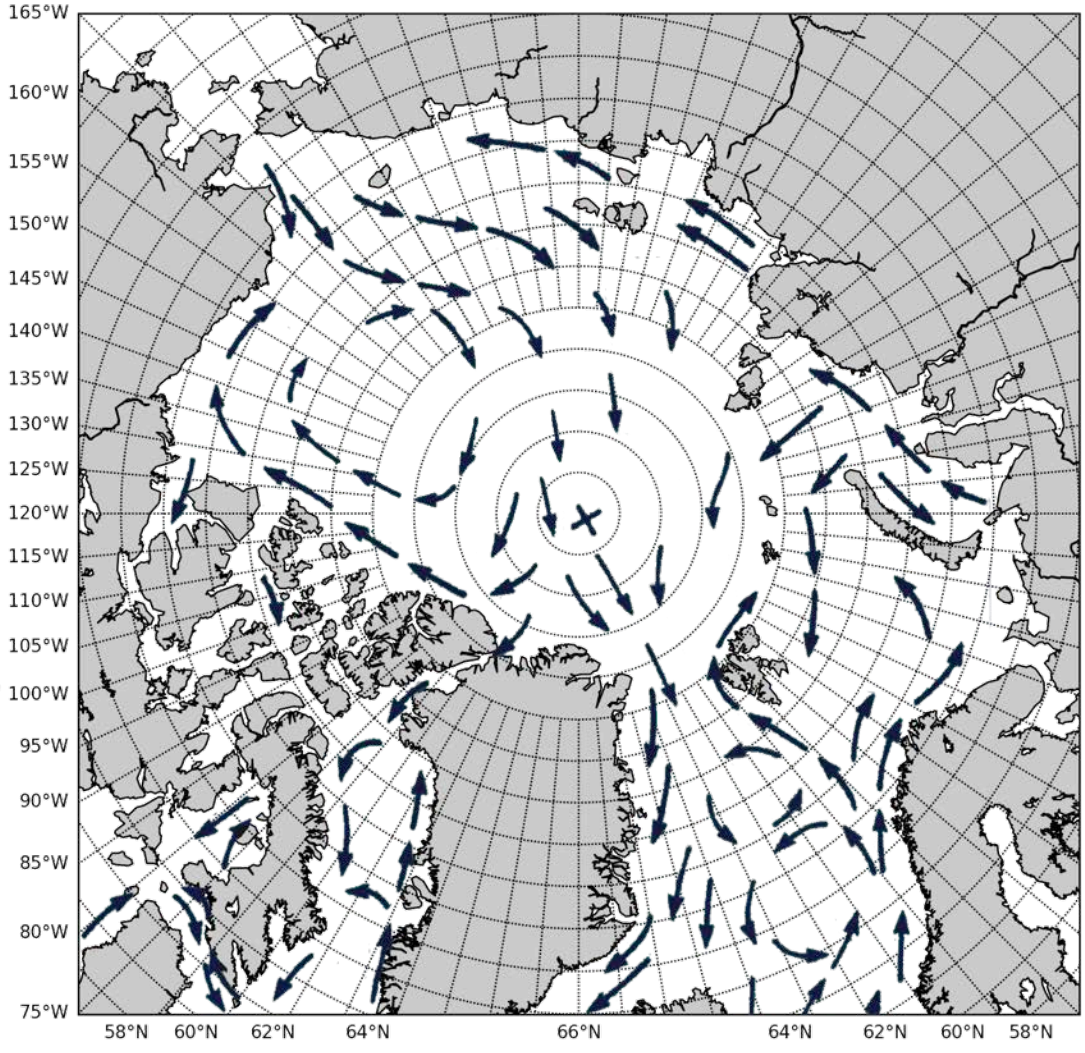

Bering Strait
180°
Chukchi Sea
USSR
Alaska
Lomonosov Ridge
Transpolar Current
90° E
Beaufort Gyre
ARCTIC SEA
Canadian Basin
Eurasian Basin
Canada
North Pole
Fram Strait
Spitsbergen
Nares Strait
Baffin Bay
GREENLAND SEA
Greenland
90° W
Hudson Bay
NORWEGIAN SEA
Norway
Davis Strait
West Greenland Current
East Greenland Current
Iceland
Irminger

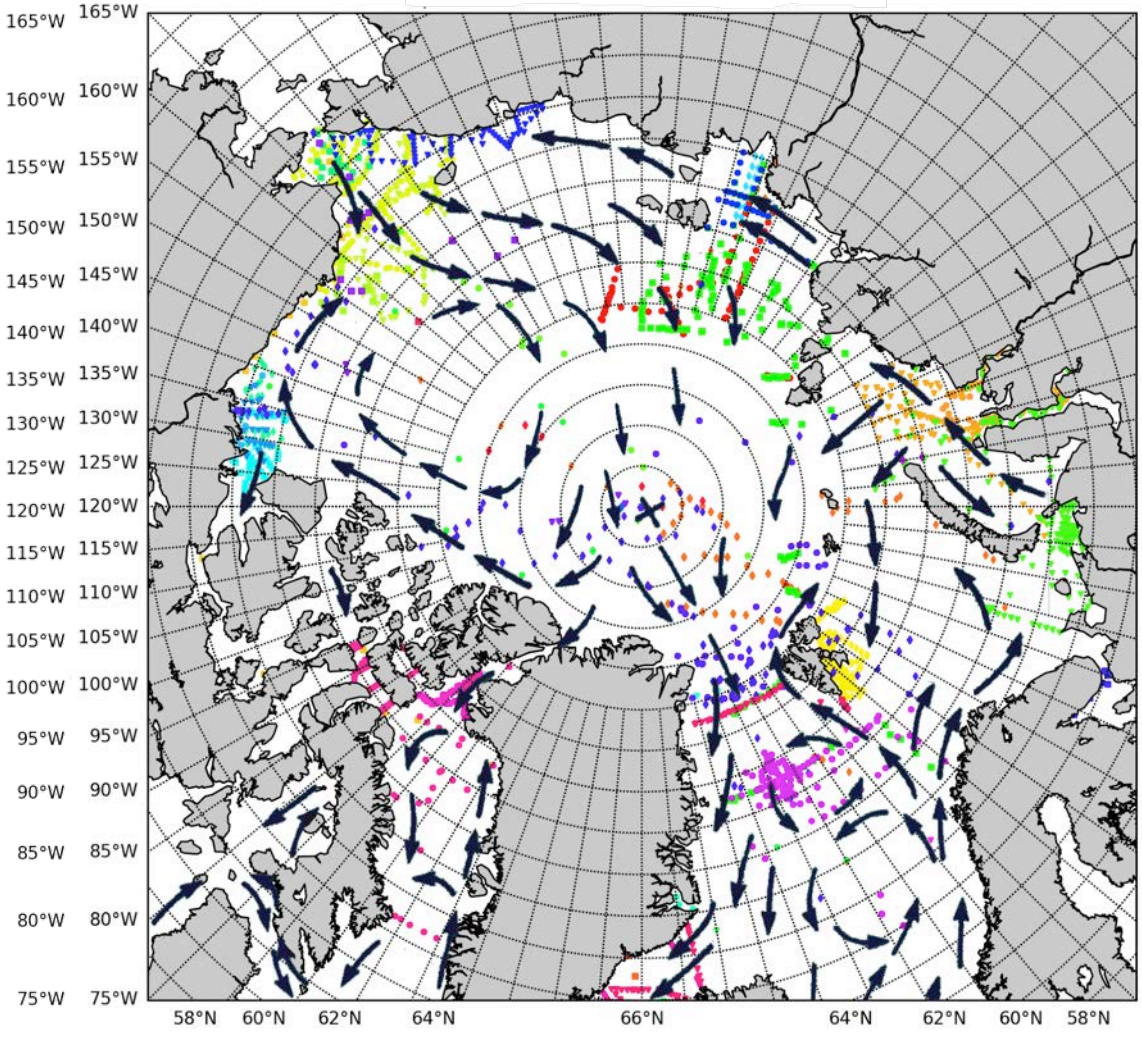
Define Arctic Water Masses

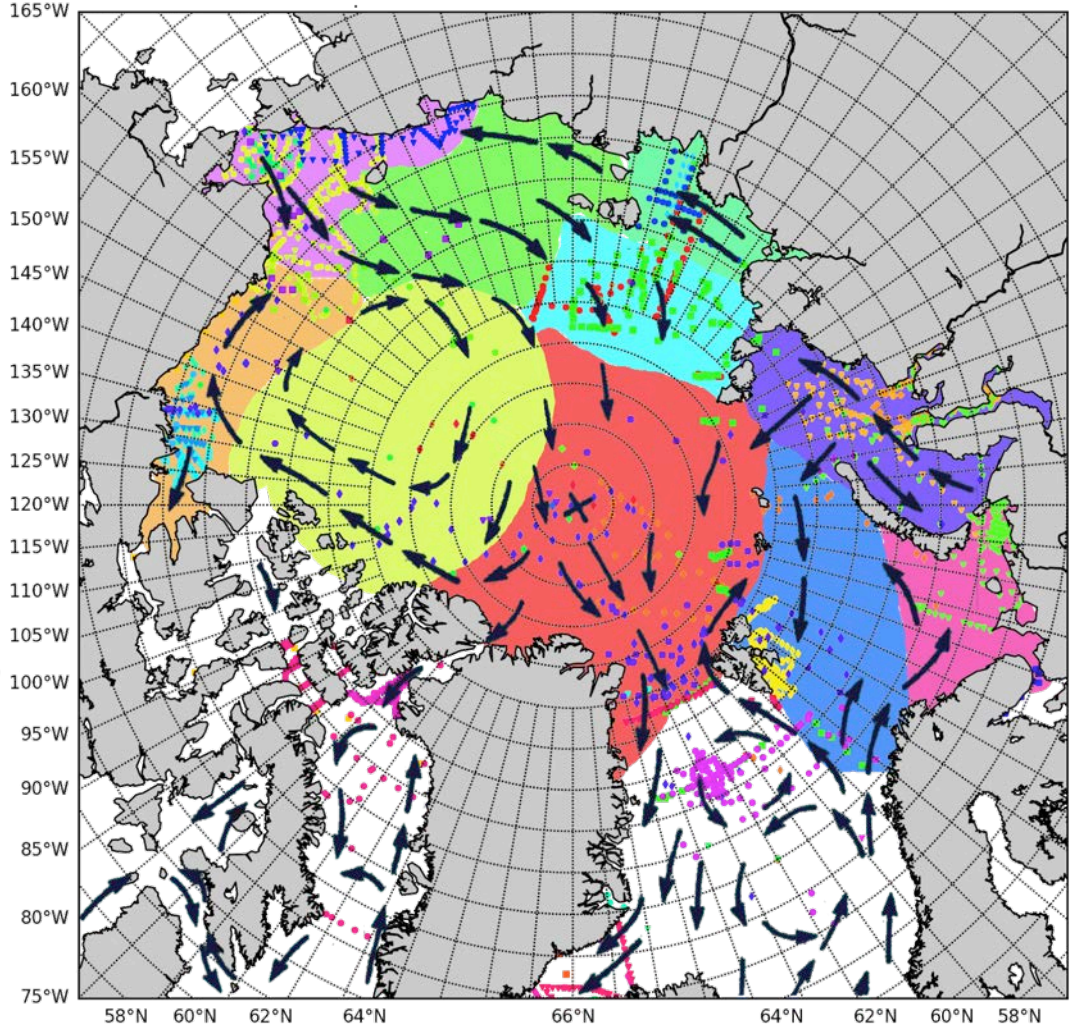
Nature -
where does water originate from?

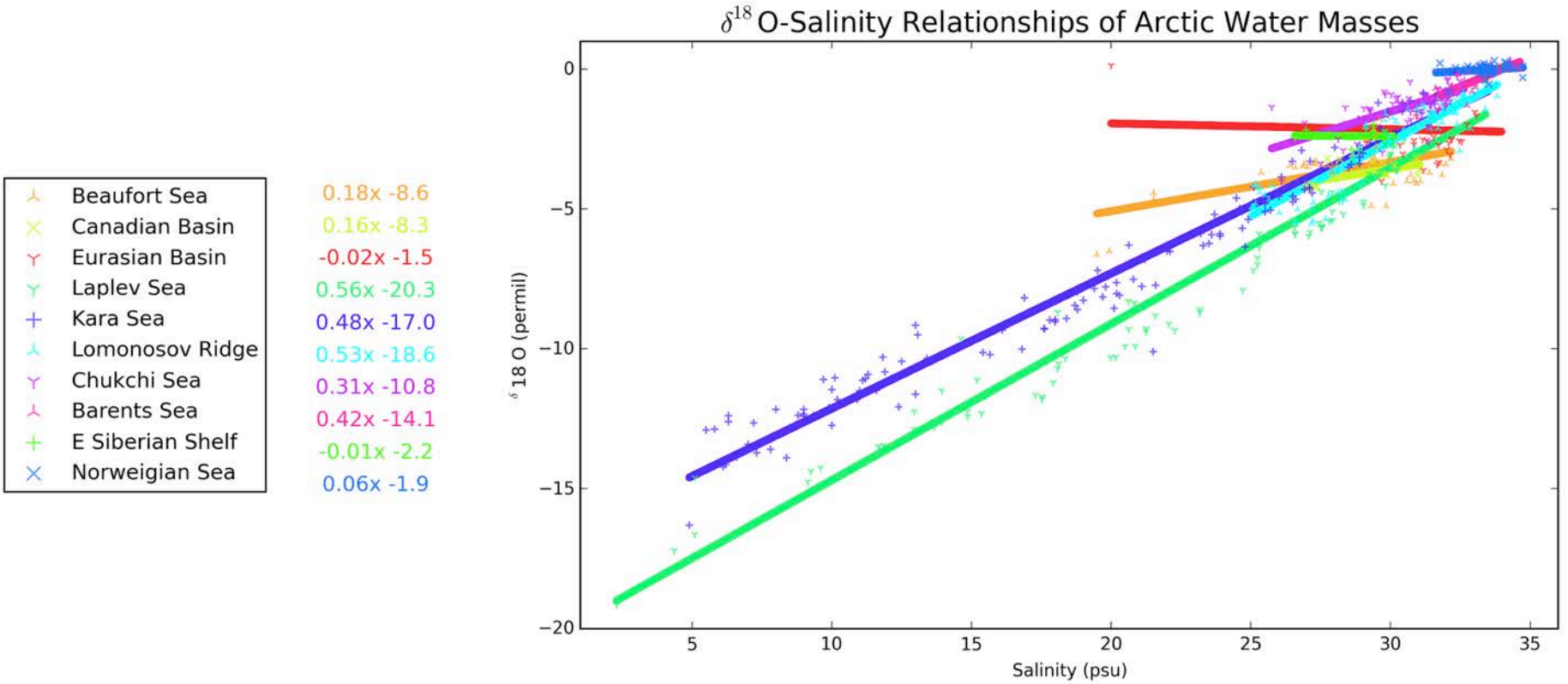
Nurture -
where has it been?

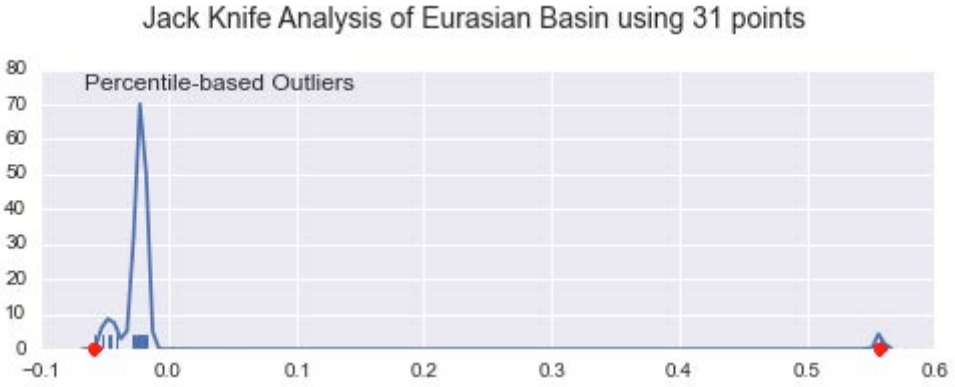
Unique qualities.

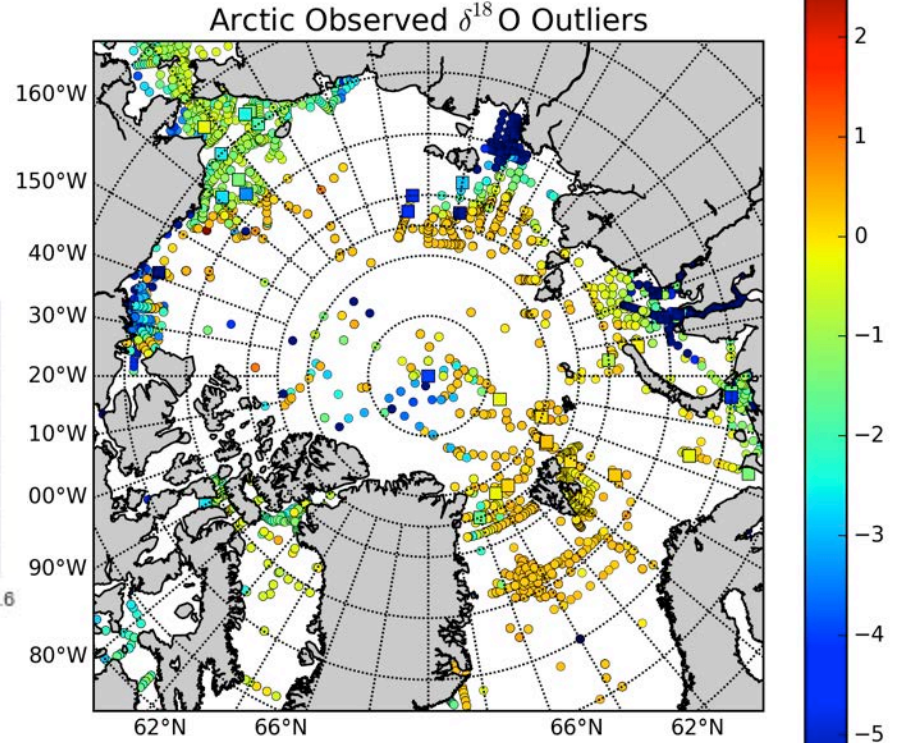

165°W
160°W
155°W
150°W
145°W
140°W
135°W
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
58°N
60°N
62°N
64°N
66°N
64°N
62°N
60°N
58°N


165°W
160°W
155°W
150°W
145°W
140°W
135°W
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
58°N
60°N
62°N
64°N
66°N


165°W
160°W
155°W
150°W
145°W
140°W
135°W
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
58°N
60°N
62°N
64°N
66°N
64°N
62°N
60°N
58°N


δ^{18} O-Salinity Relationships of Arctic Water Masses
Beaufort Sea
Canadian Basin
Eurasian Basin
Laplev Sea
Kara Sea
Lomonosov Ridge
Chukchi Sea
Barents Sea
E Siberian Shelf
Norweigian Sea
0.18x -8.6
0.16x -8.3
-0.02x -1.5
0.56x -20.3
0.48x -17.0
0.53x -18.6
0.31x -10.8
0.42x -14.1
-0.01x -2.2
0.06x -1.9
δ 18 O (permil)
Salinity (psu)
0
−5
−10
−15
−20
5
10
15
20
25
30
35

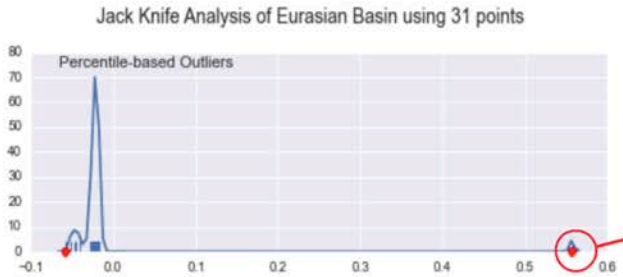




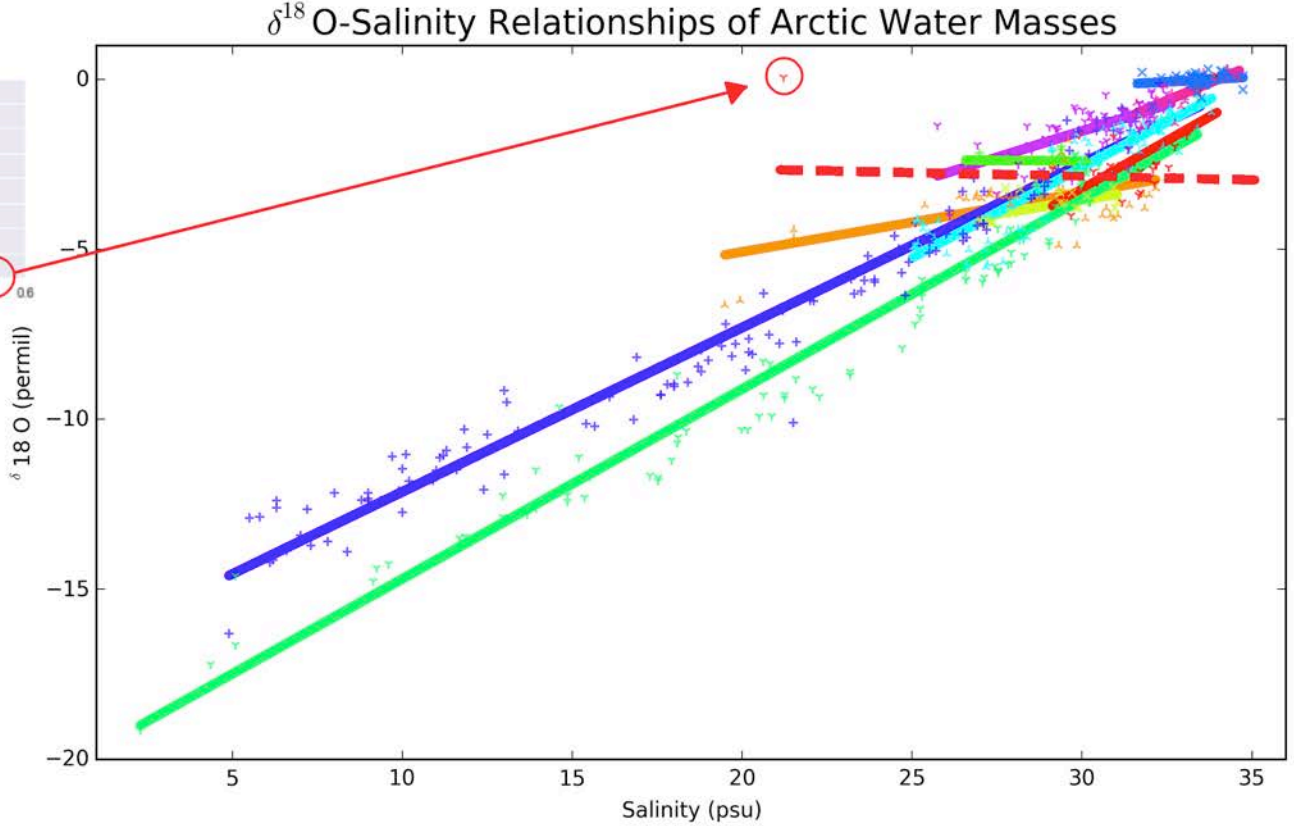
Eurasian Basin

id	sig	lat	lon	m	y	dep	temp	sal	d18o	notes	ref
17892	-0.05	0.00	81.00	9	1980	0	-1.80	33.48	-0.26	OUTLIER!	Ostlund and Hut (1984)
18115	-0.04	0.00	90.00	10	1978	0	-99.90	29.67	-4.00	OUTLIER!	Ostlund and Hut (1984)
18067	0.56	3.00	80.00	6	1984	0	-1.20	20.00	0.14	OUTLIER!	Ostlund and Grall (1993)
18039	-0.06	6.00	81.00	6	1983	2	-1.65	33.97	0.12	OUTLIER!	Ostlund and Grall (1993)
15390	-0.05	40.00	82.00	8	1993	9	-1.75	33.66	0.04	OUTLIER!	Frank (1996)
171	-0.04	42.00	85.00	8	1991	5	-1.74	33.47	-0.29	OUTLIER!	Bauch et al (1995)

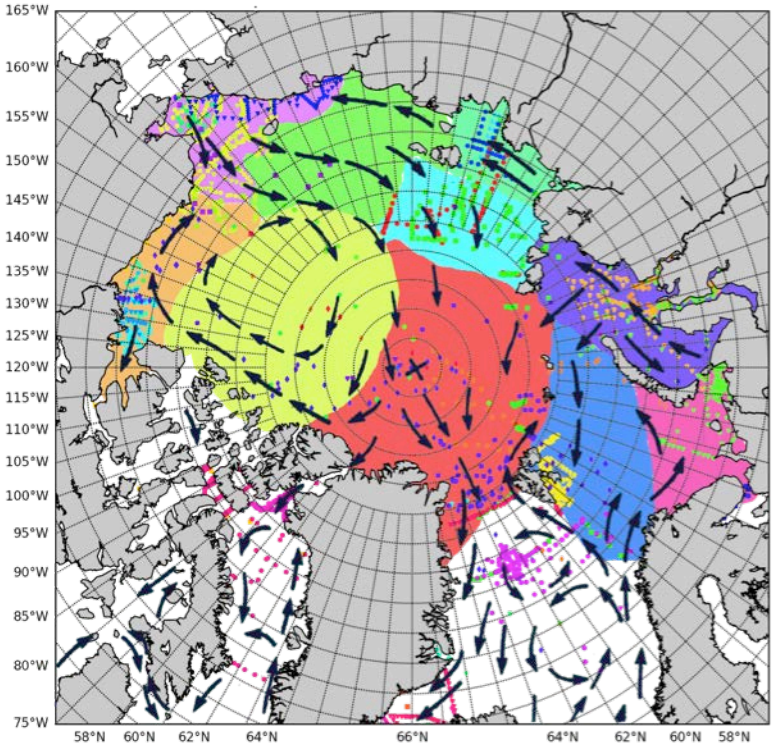
Statistics for outliers

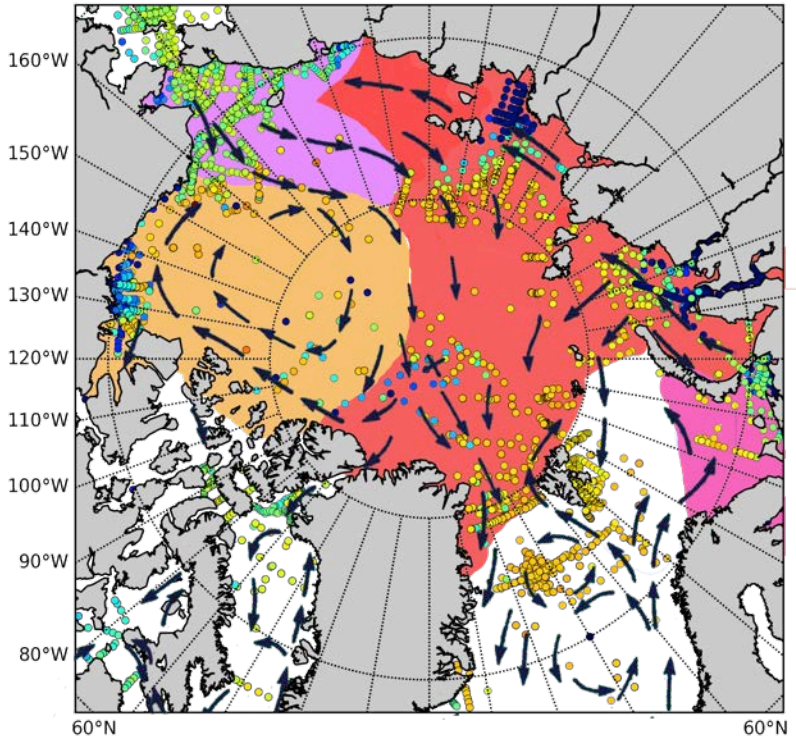


Beaufort Sea	0.17x -8.6
Canadian Basin	0.16x -8.4
Eurasian Basin	0.57x -20.3
Laplev Sea	0.56x -20.3
Kara Sea	0.48x -17.0
Lomonosov Ridge	0.53x -18.6
Chukchi Sea	0.31x -10.8
Barents Sea	0.42x -14.1
E Siberian Shelf	-0.01x -2.2
Norweigian Sea	0.06x -1.9



Redefined Water Masses





Summary

Goal:
To better understand the Arctic Ocean's complex circulation.

Accomplishments:
- Identified estimated-calculated discrepancies.
- Examined regional temporal and spatial distribution to define water masses.
- Used Jackknife to statistically analyze the water masses ^{18}O-S relationships.
- Consolidated ten water masses into four water masses.

Future Work

- Application of Jackknife slope analysis to improve regional δ^{18}O-S relationships that better define water masses and track their sources, pathways, and interactions in global ocean circulation.
- Account for temporal variation in the Global Gridded Data Set.
- Representation of ocean components along isopycnals.
- Collect additional oxygen-18 data by reviewing non-English language scientific publications

References

Bauch, D., et al. (2010), Changes in distribution of brine waters on the Laptev Sea shelf in 2007. *Journal of Geophysical Research 115*, C11.

Bauch, D., P. Schlosser, and R. Fairbanks (1995), Freshwater balance and the source of deep and bottom waters in the Arctic Ocean inferred from the distribution of H218O. *Progress in Oceanography 35*: 53-80.

Craig, H., and L. I. Gordon (1965), Deuterium and oxygen 18 variations in the ocean and the marine atmosphere. In E. Tongiori (Ed.) *Proceedings of a Conference on Stable Isotopes in Oceanographic Studies and Paleotemperatures,* Spoleto, Italy.

Dansgaard, W. (1964), Stable isotopes in precipitation. *Tellus 16*, 436-468.

Grabs, W. E., F. Portmann, and T. De Couet (2000), Discharge Observation Networks in Arctic Regions: Computation of the River Runoff into the Arctic Ocean, Its Seasonality and Variability. In Lewis, E.L., Jones, E.P., Lemke, P., Prowse, T.D., and P. Wadhams (Eds.), *Freshwater Budget of the Arctic Ocean*. Boston: Kluwer Academic Publishers, 249-65.

Létolle, R., et al. (1993), ^{18}O abundance and dissolved silicate in the Lena delta and Laptev Sea (Russia). *Marine Chemistry 43*, 47-64.

LeGrande, A.N., and G. A. Schmidt (2006), Global gridded data set of the oxygen isotopic composition in seawater. *Geophysical Research Letters 33*.

Schmidt, G. A., G. R. Bigg, and E. J. Rohling (1999), Global seawater oxygen-18 database - v1.21. http://data.giss.nasa.gov/o18data/

Acknowledgements

Allegra LeGrande
Susan Meabh Kelly
Gavin Schmidt
Matthew Pearce
Colleagues at GISS
NYCRI
NASA GISS
NASA GSFC